Diffractive Photoproduction in the Framework of Fracture Functions.

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Abstract

Recent data on diffractive photoproduction of dijets are analyzed within the framework of fracture functions and paying special attention to the consequences of the use of different rapidity gap definitions in order to identify diffractive events. Although these effects are found to be significant, it is shown that once they are properly taken into account, a very precise agreement between diffractive DIS and diffractive dijet photoproduction emerges without any significant hint of hard factorization breaking.

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Introduction

Recent years have seen a renewed interest in diffractive physics and specifically, in the possibility of using hard diffractive processes in order to investigate 'at parton level' diverse features of diffraction [1].

The success of Regge theory in the phenomenological description of soft diffraction [2] has naturally encouraged most analyses to use not only the language but also many critical hypothesis of that approach but in the hard regime and including simultaneously elements of perturbative QCD[1, 3, 4]. In this way, issues like the 'parton content of the pomeron' or the 'factorization properties of the pomeron parton densities' have become the center of active experimental programs and intense theoretical debates [5].

This concoction of perturbative QCD and Regge ideas has shown to be quite successful, from the phenomenological point of view, when applied individually to an increasingly large set of diffractive deep inelastic scattering data [6, 7], at least as a first approximation, and also to diffractive processes within hadron-hadron collisions [8]. However, it seems to have serious problems when it is meant as a processes independent description of both sets of data [9]. This fact could indicate a breakdown either of universality in the ingredients coming form the Regge picture, due for instance to an unexpected energy dependence in the pomeron probability density [11], or in the hard factorization property assumed in the QCD inspired component of the treatment [9, 10, 3].

Alternatively to the above mentioned approach, many hard diffractive processes, including diffractive DIS, can be treated rigorously within perturbative QCD -and without caring about the validity of the hypothesis implicit in the Regge approach- using the framework of fracture functions [12]. This framework was originally thought to deal with semi-inclusive processes within QCD in a fully consistent way [13], and more recently it has been shown to be particularly successful in the phenomenological description of diffractive DIS and leading baryon production, and also in the analysis of departures from the standard Regge hypothesis, already found in the available data [12].

In the present paper, the framework of fracture functions is applied to diffractive photoproduction of dijets [14, 15]. This is meant not only as

a test of the general approach and as a complementary verification of the parameterizations extracted from DIS, but also as a test of the hard factorization property assumed for fracture functions in the case of hadron-hadron collisions. At variance with the case of diffractive DIS [16], the factorization property of fracture functions, which is crucial in order to compute the sizeable contribution of resolved photons to the photoproduction processes [17, 14, 15], may be challenged by the occurrence of soft interactions before the hard scattering takes place in diffractive hadron-hadron collisions [3, 10].

Performing this analysis, it has been found that the use of non-equivalent rapidity gap definitions in order to identify diffractive processes in the different experiences conspires strongly against the above mentioned tests. In the language of fracture functions, to adopt different gap definitions implies that only certain components of the whole fracture function are tested, suppressing or enhancing contributions coming from certain kinematical regions, and leading seemingly to a factorization breakdown. However, here it is shown that these effects can be properly taken into account yielding a very precise agreement between diffractive DIS and diffractive dijet photoproduction, without any significant hint of hard factorization breaking.

In the following section, the standard procedure used in the extraction of diffractive parton densities or, alternatively, fracture functions in diffractive DIS is reviewed giving emphasis to the issue of the use of different definitions for the diffractive event. Then, we proceed to the computation of diffractive photoproduction of dijets analyzing the consequences of different conventions about rapidity gaps for this kind of process. Finally, results from the computation are compared with available data from the ZEUS and H1 collaborations [14, 15] and conclusions are presented.

Parameterizations:

It is customary to analyze diffractive DIS in terms of a so called 'diffractive structure function' $F_2^{D(3)}$, defined through the triple-differential scattering cross section

$$\frac{d^3\sigma^D}{d\beta\, dQ^2\, dx_{I\!P}} \equiv \frac{4\pi\alpha^2}{\beta\, Q^4}\left(1-y+\frac{y^2}{2}\right) F_2^{D(3)}(\beta, Q^2, x_{I\!P})\,, \tag{1}$$

in the usual kinematical variables

$$Q^2 = -q^2 \quad x_{I\!\!P} = \frac{q \cdot (P - P')}{q \cdot P} \quad \beta = \frac{Q^2}{2q \cdot (P - P')} = \frac{x}{x_{I\!\!P}}\,, \tag{2}$$

where q, P, and P' are the momenta of the virtual boson, of the incident proton, and of the final state proton, respectively, and $y = Q^2/(x\,s)$. Both the cross section and the structure function defined in this way, include an implicit integration over a given range of the variable $t = (P - P')^2$, and in order to identify diffractive events, different selection criteria are commonly used. From a theoretical point of view, the most straightforward method is the positive identification of a final state proton carrying a substantial fraction of the incoming proton momentum. However, and mainly for technical reasons, the most widely used method retains events with a pseudo-rapidity gap (absence of hadronic activity) between the two hadronic systems in which the hadronic final state is conventionally divided [5].

In the Regge inspired approach, the diffractive structure function is assumed to be given by the product of the probability $f_{I\!\!P/p}(x_{I\!\!P}, t)$ to find a pomeron in the incoming proton, which only depends on the variables $x_{I\!\!P}$ and t, and a 'pomeron structure function' $F_2^{I\!\!P}(\beta, Q^2)$, given by parton densities which behave according to Altarelli-Parisi evolution equations and factorize as ordinary parton distributions [4]. Aside from the issue of the validity of these assumptions, it is clear from the preceding paragraph that non equivalent selection criteria for diffractive events can lead to the extraction of non equivalent pomeron probability densities and pomeron parton distributions, eventually non universal [18].

Alternatively, in reference [12], it has been shown that the diffractive structure function defined as in Eq.(1) just represents the low $x_{I\!\!P}$ limit of a more general semi-inclusive process, which in perturbative QCD can be rigorous and thoroughly described using fracture functions.

In leading order, fracture functions account for target fragmentation components in the full semi-inclusive deep inelastic lepton-proton scattering cross section with an identified proton in the final state. These components are neglected in the most usual approach based only in ordinary proton parton distributions $q_i^p(x, Q^2)$ and proton fragmentation functions $D_i^p(z, Q^2)$, which accounts for current fragmentation processes.

Then, the full semi-inclusive cross section,

$$\frac{d^3\sigma^{p/p}}{dx\,dQ^2\,dz} = \frac{4\pi\alpha^2}{x\,Q^4}\left(1-y+\frac{y^2}{2}\right) \times \left[x\sum_i e_i^2 q_i^p(x,Q^2)\times D_i^p(z,Q^2) + x\sum_i e_i^2 M_i^{p/p}(x,z,Q^2)\right], \tag{3}$$

includes an additional contribution that can be written as a sum of hard scattering cross sections weighted by the fracture function densities corresponding to the different quark flavors i for protons fragmenting into protons $M_i^{p/p}(x,z,Q^2)$, which can then be understood as the probabilities to find a parton of flavor i in an already fragmented proton [13].

In Eq.(3), the variable z is, as usual, the ratio between the energy of the final state proton and that of the proton beam in the center of mass of the virtual photon-proton system. For very forward protons $z \simeq 1 - x_{I\!P}$ and the current fragmentation components in the cross section fade away highlighting the relation between fracture functions and diffractive or leading proton structure functions.

As for ordinary structure functions, although the scale dependence of fracture functions can be computed within perturbative QCD, they are essentially nonperturbative objects which can not be obtained from first principles in a perturbative analysis. However they can be extracted from global QCD analysis of experimental data. In reference [12] it has been shown that a very simple parameterization in the variables β and $x_{I\!P}$ and at an initial scale $Q_0^2 = 2.5\,GeV^2$ for singlet quarks and gluons in the corresponding fracture function,

$$xM_i^{p/p}(x_{I\!P},\beta,Q_0^2) = N_i\,\beta^{a_i}(1-\beta)^{b_i} \times \{\beta x_{I\!P}^{\alpha_i} + C_{LP}(1-\beta)^{\gamma_{LP}}[1+a_{LP}(1-x_{I\!P})^{\beta_{LP}}]\} \tag{4}$$

reproduces both diffractive and leading proton data as complementary regimes of the same semi-inclusive process without need to rely in Regge model assumptions. There, the values for the parameters were obtained fitting simultaneously diffractive and also leading proton positron-proton DIS data from the H1 Collaboration [6, 19] and can be found in reference [12]. The former data fix the low $x_{I\!P}$ behavior of the fracture function while the latter do the same but for larger values of $x_{I\!P}$.

Regarding the diffractive selection criterion for DIS data, H1 retains events having a rapidity gap that spans at least the region $3.3 < \eta < 7.5$, assuming that this gap definition guarantees the dominance of single diffractive (semi-inclusive) events like $e^+(k) + p(P) \to e^+(k') + X + p(P')$, where X is a generic hadronic final state, and $p(P')$ the final state proton [6]. This assumption in fact seems to be justified, at least for this kind of process and in the kinematical regime of the experiment, given the remarkable agreement between the outcome of the parameterization and data obtained by ZEUS [7] detecting the final state proton, as pointed in [12]. However, the assumption not necessarily holds for other gap definitions, processes, or kinematical regimes. In the following section we will show that diffractive dijet photoproduction provides an illustrative example of this situation.

Photoproduction

Both the ZEUS and H1 Collaborations have presented results of diffractive dijet photoproduction experiments at HERA[17, 14, 15]. These processes, also depicted by $e^+(k)+p(P) \to e^+(k')+X+p(P')$, are characterized by the presence of at least two jets in the hadronic final state X that accompanies the outgoing proton $p(P')$ and positron $e^+(k')$. The diffractive criterion is implemented imposing upper limits for the pseudo-rapidity η^{had}_{max} of the most forward particle belonging to the hadronic state X and with energy in excess of 400 MeV ($\eta^{had}_{max} < 3.2$ in the case of H1, while ZEUS takes $\eta^{had}_{max} < 1.8$).

The photon interaction in these processes can be either of direct or of resolved nature, making convenient the introduction of the variable x_γ, which measures the fraction of the photon momentum that takes part in the hard interaction. The direct component of the diffractive dijet cross section can be straightforwardly computed replacing in the inclusive (non-diffractive) cross section, the usual proton parton distributions by the corresponding fracture densities $xM^i_{p/p}(x_{I\!P}, \beta, \mu^2)$ and allowing an integration over the pertinent range in $x_{I\!P}$ [20],

$$\sigma^{direct} = \int dy\, f_{\gamma/e}(y) \int dx_{I\!P} \int d\beta\, xM^i_{p/p}(x_{I\!P}, \beta, \mu^2) \int d\hat{p}_T^2 \frac{d\hat{\sigma}_{i+\gamma\to k+p}}{d\hat{p}_T^2}, \qquad (5)$$

where $f_{\gamma/e}(y)$ is the flux of photons from the positron, $\hat{p}_T$ the transverse momentum of the outgoing partons, μ the scale at which the strong coupling constant is evaluated, and $\hat{\sigma}_{i+\gamma\rightarrow k+p}$ the parton-photon cross section with two partons in the final state.

For the resolved component, the procedure would be analogous to the preceding one with the proviso that in this case no formal proof of hard factorization guarantees it,

$$\sigma^{resolved} = \int dy\, f_{\gamma/e} \int dx_\gamma f_{j/\gamma} \int dx_{I\!P} \int d\beta\, x M^i_{p/p} \int d\hat{p}_T^2 \frac{d\hat{\sigma}_{i+j\rightarrow k+p}}{d\hat{p}_T^2}. \qquad (6)$$

Here, $f_{j/\gamma}(x_\gamma, \mu^2)$ denotes parton distributions in the photon, $\hat{\sigma}_{i+j\rightarrow k+p}$ the parton-parton cross section with two partons in the final state. For simplicity we have dropped the arguments for the densities and also the sums over the partonic indexes i and j.

In any case, before dealing with the issue of hard factorization and making comparisons between the parameterization and the available data sets, it is imperative to analyze the compatibility between the gap criteria implicit in them.

Given that the profile of the hadron activity as a function of the pseudorapidity of the most forward hadron, and thus the consequences of a given gap convention, depends on various non perturbative hadronization effects, in what follows we simulate them using a variant of the Monte Carlo generator POMPYT 2.6 [21], modified in order to include parameterizations for fracture functions.

The inclusion of fracture functions in POMPYT imply to abandon explicitly the pomeron flux factorization hypothesis, modifying both the shape and scale dependence of the diffractive parton densities as a function of $x_{I\!P}$, as required by DIS data [12]. In what follows, all the simulations are computed using the best fit to diffractive DIS data, denoted as SET A in reference [12] as the fracture function, and SaS 2M from reference [22] for the photon.

In Figure (1), dijet photoproduction events generated in the kinematical regimes of H1 (Fig. 1a) and ZEUS (Fig. 1b) are shown as a function of η^{had}_{max}. The thick vertical lines represent the upper cuts in η^{had}_{max} applied by each collaboration.

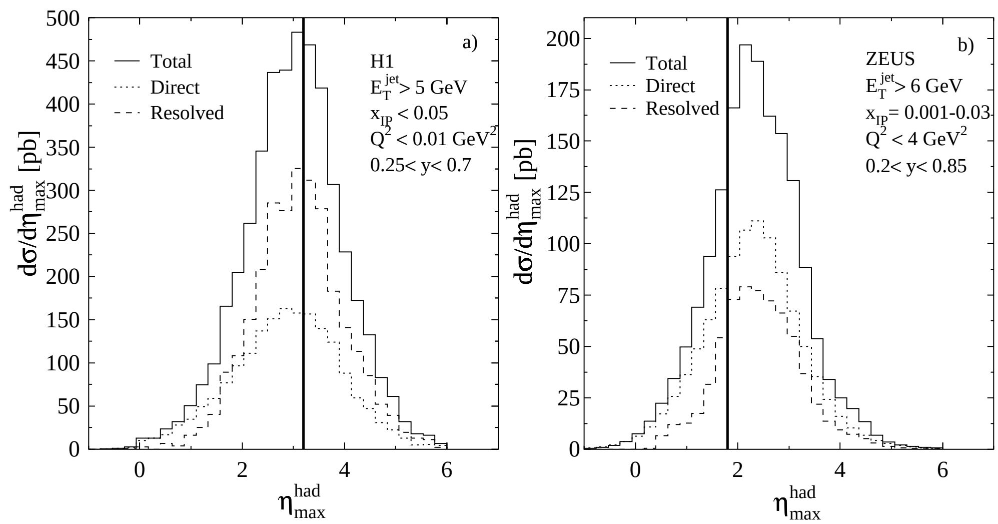

Figure 1: Dijet photoproduction events generated in the kinematical regimes of the **a)** H1 and **b)** ZEUS experiments

It is worthwhile noticing that even for the same kind of process, the different kinematical regimes covered by both experiments given for example by cuts in the transverse energy E_T and pseudo-rapidity η of the two most energetic jets, etc., yield rather different distributions in η_{max}^{had} and thus, are affected in a different way even for the same pseudo-rapidity gap definition. For ZEUS, approximately 25 % of the total number of events are concentrated at $\eta_{max}^{had} < 1.8$, while for H1 kinematics approximately 10 % of them survives the same constraint.

In the computation, an additional multiplicative normalization factor has been applied to the fracture function in order to take into account the fact that the original parameterization was adjusted to data already filtered by a gap definition. This normalization factor can be defined in a first approximation as the ratio between the total number of dijet photoproduction events and those that satisfy the gap definition implicit in diffractive DIS data, both quantities computed in the kinematical range where the simulation takes place. In the present case, this rate is found to be 1.14 for ZEUS and 1.61 for H1.

Figures (2) and (3) show the comparison between dijet photoproduc-

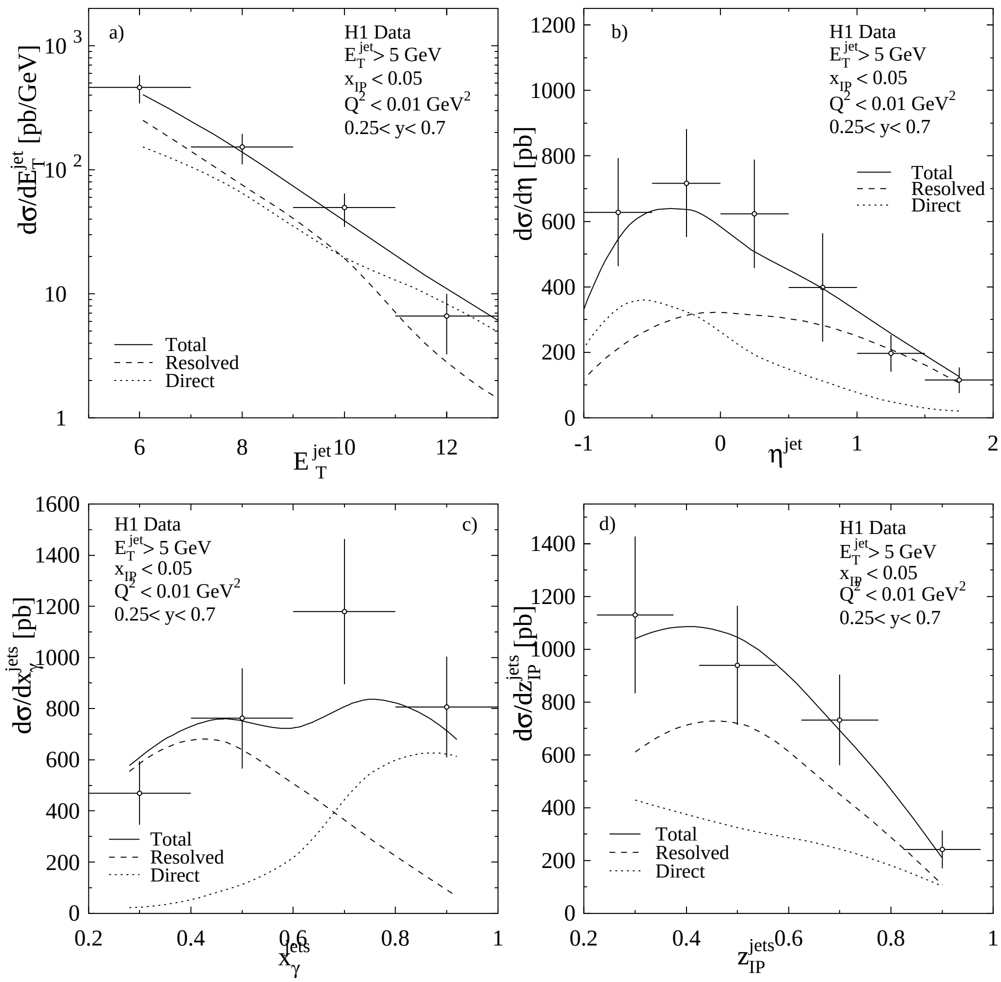

Figure 2: Comparison between H1 dijet photoproduction data and the outcome the fracture function parameterization.

tion data [14, 15] and the outcome of the fracture function parameterization obtained from DIS. The cross sections are computed in picobarns and as functions of the hadronic level variables defined within each experiment.

As it can be seen, the agreement is quite good for both sets of data although the effects of taking into account the different rapidity gap conventions are large. It is important to notice that neglecting the stringent restriction applied in the ZEUS measurement ($\eta_{max}^{had} < 1.8$), the computation would have led to cross sections up to five times larger.

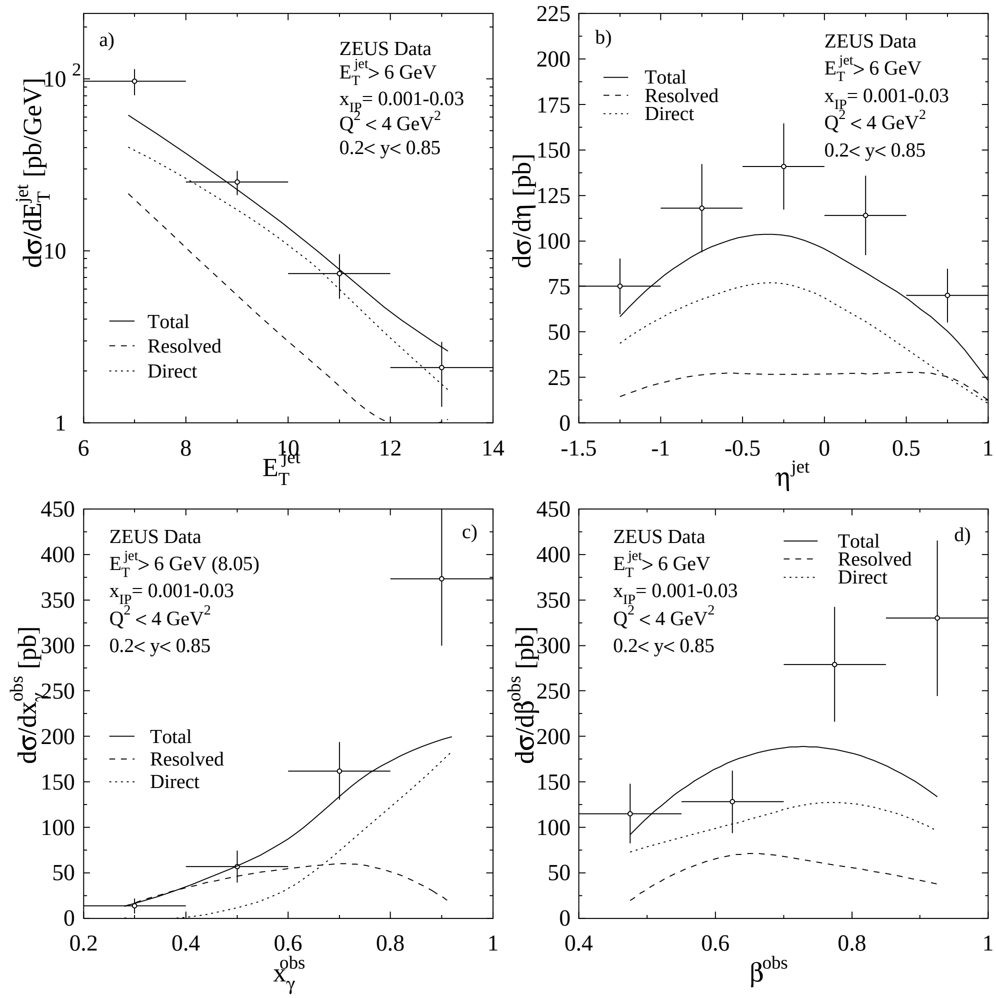

Figure 3: Comparison between ZEUS dijet photoproduction data and the outcome the fracture function parameterization.

The comparison with ZEUS data shows that the numerical results tend to underestimate the cross sections for large values of β^{obs}. This fact could indicate the need of a further adjustment in the diffractive parameterization in that region, which in fact is allowed by the present level of uncertainties in DIS data, specially at lower scales.

For H1 photoproduction data, the gap definition is very similar to that of diffractive DIS data so the effect of neglecting at all such cuts is relatively small when analyzing event distributions in variables other than η^{had}_{max}. However, if one wants to reproduce the whole picture including the η^{had}_{max}-

dependence, of course they can not be neglected and some care must be taken in order to not apply the cuts twice, as pointed by the large normalization factor.

In the precedent discussion, specifically in the computation of the normalization factor, we have assumed that the rapidity gap restriction only reduces uniformly the number of events, i.e., without changing the distribution of events in other kinematical variables. This seems to be a good approximation for the E_T and η distributions, but it is not for $x_{I\!P}$. The Monte Carlo simulation shows a clear correlation between the cuts applied in η_{max}^{had} and the mean for the distributions in $x_{I\!P}$ implying that the larger is the gap, the lower is the mean $x_{I\!P}$ proved, as shown in figure (4).

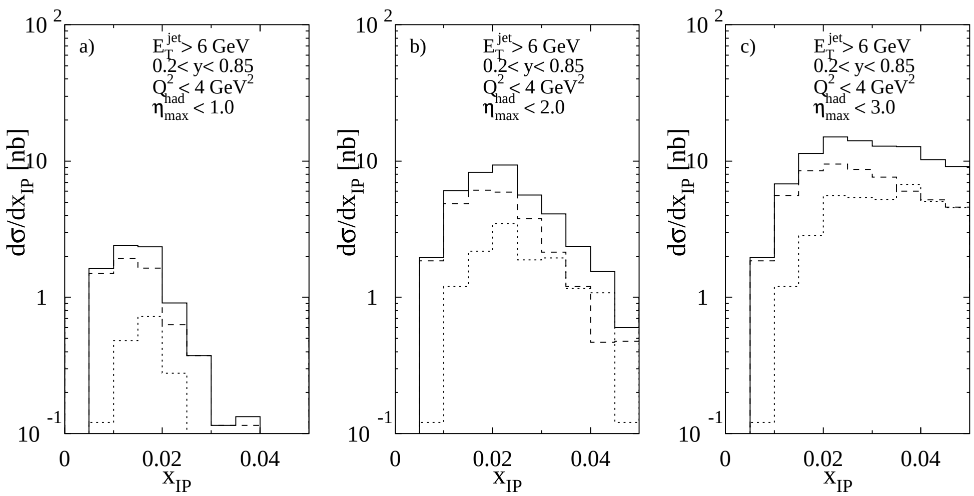

Figure 4: Distribution of dijet events as a function $x_{I\!P}$ for different rapidity gap definitions (**a**) $\eta_{max}^{had} < 1.0$, **b**) $\eta_{max}^{had} < 2.0$, and **c**) $\eta_{max}^{had} < 3.0$)

The direct consequence of the above mentioned effect is that different gap definitions weight differently contributions coming from a given range of $x_{I\!P}$, thus adding to the discrepancy between diffractive structure functions extracted from different experiments. In our approach, this inconvenience has been straightforwardly overcame computing the normalization factor for various bins in $x_{I\!P}$. The main effect of this procedure in the comparison with H1 data is to enhance the cross section at low $z_{I\!P}$ (large $x_{I\!P}$) in figure (3d) and reduce it slightly at large $z_{I\!P}$. For ZEUS, the normalization effect is small

so the correction is almost negligible.

This considerations about rapidity gap definitions apply also to the comparison between diffractive DIS and diffractive dijet production within proton-antiproton collisions at Tevatron, where large discrepancies have been observed [9, 11]. In the comparison of DIS data and these processes, the effects associated with the gap definition can even be enhanced not only because of the differences in the kinematical ranges covered but also in the extrapolation of the diffractive DIS parameterizations to rather large values $x_{I\!P}$, dominant in proton-antiproton collisions.

Hard Factorization

Regarding the issue of hard factorization, it is worth noticing that in both ZEUS and H1 photoproduction experiments, and even in the regions dominated by the contributions coming from resolved photons ($x_\gamma < 0.7$), no hints of significant factorization breaking effects are found, confirming our initial assumption about hard factorization in these kind of processes. This is particularly apparent for H1 data which contains a much larger fraction of events initiated by resolved photons and would indicate that hard factorization, if not exact, is a very good approximation.

It is also interesting to notice that at variance with the analysis of H1 data of reference [15], in the present treatment no substantial overestimate of the cross section as a function $z_{I\!P}$ is found. In reference [15] this excess was interpreted of a reduced gap survival probability [23], and an ad hoc correction factor was fixed with the data. In the present approach these discrepancies can be traced back to the non equivalence of rapidity gap definitions, which encompasses effects related to spectator interactions, but in a more predictable way.

Conclusions:

Dijet diffractive photoproduction has been analyzed in the framework

of fracture functions finding that the main effects that conspire against a unified picture for diffractive DIS and diffractive photoproduction in terms of diffractive parton distributions are related to non-equivalent criteria used to select diffractive events.

The connection between different rapidity gap definitions is model-dependent in the sense that it includes non-perturbative hadronization details. However, using a slight modification of the POMPYT Monte Carlo generator, devised in order to include in it fracture functions, a consistent and accurate picture can be drawn.

In this way, the analysis suggests that the supposed discrepancies between the diffractive parameterizations coming from these experiments are rather due to the non-universal character of rapidity gaps, than to a hard factorization breakdown, and that the potential factorization breaking mechanisms are negligible, well beyond the accuracy of the present data.

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